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# PHYSIOLOGICAL INDICES OF MENTAL WORKLOAD

**INTERIM TECHNICAL REPORT**

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13. ABSTRACT (Maximum 200 words)

We are working on an enabling technology to facilitate the development of physiological indices of mental workload that could be used in high performance aircraft. To date, we have designed and implemented the core components of a neural-network based algorithm for deriving continuous mental workload indices from continuous recordings of brain, scalp muscle, eye and heart electrical activity. We have also designed an experiment to test the adequacy of this algorithm, and have developed technologies to perform the experiment including: (1) designing a task battery to initially test the ability of the network algorithm to generalize across cognitive functions relevant to piloting aircraft; and (2) implementing a software library that could be used to efficiently present the task stimuli using the same personal computer which also collects 32 channels of electrophysiological data. We have tested the integrated system and have found it capable of providing accurate timing of task stimuli, subject responses, and electrophysiological data.

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## I. BACKGROUND

We proposed to build a data collection and software workbench, called the Workload Assessment Research workstation (WAR Station), to facilitate research on mental workload. The WAR Station is to include hardware and software for collecting electrophysiological and behavioral data associated with tasks used in mental workload research and a collection of software tools for analyzing these data with the goal of building and testing practical mental workload indices. The indices would be based on a particular neural-network analytic paradigm used in our prior research (Gevins, 1980; Gevins and Morgan, 1986, 1988). The algorithm would greatly simplify the use of neural networks for mental workload researchers since it automatically generates a neural network and selects optimal variables for classification.

Much of this system builds on hardware and software under development in other projects at SAM Technology. The major work required of this project includes

1) designing, implementing, and testing a novel neural network algorithm using a few techniques from the algorithm used in our prior research and current multilayer perceptron techniques;

2) performing an experiment to provide an initial test of the utility of our analytic approach for building practical indices of mental workload;

3) building the WAR Station by integrating workload-specific software with software and hardware components built under other projects at SAM Technology; and

4) surveying Air Force researchers to determine desirable system features and work out what data import capabilities will be needed.

These four items reflect an approved revision of our statement of work which consisted of appending the second item to our work plan and postponing integration of our system with commercial moving-base flight simulators until Phase III.

## II. SUMMARY

Report Period, 16 Dec 91 to 15 Dec 92

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Because full development of the WAR Station depends on developments of other projects being performed at SAM Technology, it is most efficient to stage in work on the WAR Station project so that the maximum effort takes place when the prerequisite technologies become available. At this time, we have completed one section of the neural network algorithm, designed a workload experiment to test our analysis approach,

developed tools for implementing neurocognitive tasks that can be used to manipulate mental workload, and integrated a recently completed electrophysiological recording system with task presentation software. These efforts reflect about six person months of effort charged to this project.

## III. PROGRESS REPORT

### Neural Network Algorithm

An extension to the Viglione-Joseph neural network (Joseph, 1961; Viglione, 1970; Gevins, 1980; Gevins and Morgan, 1986, 1988) to handle more than two-class pattern recognition problems was derived then implemented using the C++ programming language. Presently, the algorithm automatically creates a network that is, effectively, a two layered network with lateral inhibition between second layer neural units. The first layer consists of neural units that implement linear or quadratic discriminant functions. The outcome of this algorithm is an initial approximation of a suitable network. We have tested it with Fisher's iris data set (Fisher, 1936). Fisher's data set has four variables for three different kinds of iris's. Using Jackknife resampling methods (Efron, 1982), average overall cross-validation classification performance was 0.973 while average performance on the data used to set up the networks for each Jackknife sample was 0.98. These results are comparable to results reported for statistical classification methods as well as common neural network algorithms (Weiss and Kulikowski, 1991).

The next step in this development is to implement algorithms to refine the network by adjusting connection weights between neural units, automatically add neural units to the network if needed, and finding alternative combinations of variables that have higher classification power. The final step will be to convert network outputs into a continuous variable and to demonstrate the feasibility of using it as a continuous index of mental workload. No revisions to the techniques described in the Phase II proposal are anticipated at this time.

### Experiment for Testing the Algorithm

*Design of the Experiment*

The experiment consists of recording EEGs, eye movement and blink potentials, and EKG while subjects perform a battery of neurocognitive tasks. The task battery is composed of several task families which differ in the variety and/or degree of mental resources involved. Component tasks within each family differ, by design, in mental workload; verification is by performance variables and the Subjective Workload Assessment Test (SWAT). These data are used to find electrophysiological indices of mental workload that work across task families and subjects. Performance (reaction time and accuracy) and SWAT scores are used to separate tasks into four levels of mental workload. Using data from three of these levels, the network algorithm is used to construct a network that implements a continuous index of mental workload. The network is then tested on its ability to place the data from the excluded level within an expected interval of the index. This analysis is performed with two subsets of task families to test generalizability of the index across tasks and with two subsets of subjects to test generalizability across subjects; Jackknife resampling methods (Efron, 1982) are used to obtain improved estimates of generalizability performance.

Each subject performs the whole battery of tasks twice, using a different randomized order each time. During the first run, no electrophysiological recordings are made and, for each task, additional task trials are given until subjects respond correctly at least

80% of the time, indicating that they have understood the requirements of the task. During the second run, 16-32 channels of EEG at the standard 10-20 positions are recorded continuously throughout each task with a passband of 0.05 to 50 Hz and referenced to digitally linked mastoids. Fifteen trials or less are given for each task with maximum play time on any one task limited to 2 minutes. After each task, subjects evaluate their experience on the task by performing the SWAT.

*Cognitive Performance Tasks*

Our strategy is to test the workload classification algorithm for generalizability across tasks by designing several types of tasks that each vary in the degree of workload that they impose and the type of cognitive operations that they require. The mental workload index is then tested for generalizability across tasks, providing a strong test that the index is not peculiar to a particular task family or type of cognitive operation. In designing the battery an effort was made to explicitly test cognitive functions relevant to piloting an aircraft, including:

*Working Memory*--maintaining information for several seconds while it is being utilized in the context of a mental task;

*Visuomotor Tracking*--sustained execution of adaptive actions in response to some continuously varying perceptual event;

*Dynamic Visuospatial Reasoning*--rapidly coordinating behavior with information about the location and speed of moving objects; and,

*Divided Attention*--simultaneously allocating attention to multiple tasks.

Each of these types of tasks have been studied in detail (Pelligrino & Hunt, 1990; Baddeley, 1992; Poulton, 1974; Wickens, 1984). Our testing protocol examines the physiological concomitants of increases in the workload imposed on each of these types of operations.

*Task Battery*

For each of the mental faculties listed above, except for Dynamic Visuospatial Reasoning, we have specified two task families which differ in the form of the information processed; in one, spatial information must be processed while the other requires symbolic processing. The tasks are presented visually on a computer screen and require speeded finger-press responding.

*Working Memory*

For this category, the basic idea is to present stimuli in a continuous sequence and require the subject to compare recent stimuli with those earlier in the sequence. In the family of tasks oriented toward symbolic processing, the task is to determine whether or not a stimulus object matches the previous one. For the next higher mental workload level, the task is to compare the present stimulus with the second prior stimulus. The third level will require comparing the prior stimulus with the second prior stimulus. The fourth level will be the same as the second level but stimuli will be presented at a faster pace. The task family oriented toward spatial processing will be the same except that the task will be to determine whether or not stimuli appeared in the same spatial location on a circle (Mishkin et al., 1983).

### *Visuomotor Tracking*

For the task family oriented toward spatial processing, the task is to keep a horizontally moving cursor centered on the computer screen using continuous controllers in the right and left hands to influence right and left cursor movement respectively (Jex, 1966). Cursor motion reflects the output of an unstable control system characterized by a transfer function with one or more poles, gain, and an instability parameter; the control system tends to amplify any deviation from the central cursor position. The first three mental workload levels correspond to one-, two-, and three-pole systems respectively. The instability parameter is gradually increased until the operator loses control and the cursor exits one side of the screen. The fourth workload level is the same as the second level except that the cursor also exhibits vertical deviations from center; vertical deviations must be nullified by a right or left button press for up or down motion respectively. For the task family oriented toward symbolic processing, cursor position is given by a numerical display (or two in the case of the fourth level) instead of graphically. The task is to keep the read-out at zero as closely as possible.

### *Dynamic Visuospatial Reasoning*

The basic idea for the task family in this category is to launch a "missile", which appears on the bottom of the computer screen, in such a way that it intercepts a target object traveling horizontally across the computer screen (Hunt et al., 1988). The vertical position of the target differs randomly from trial to trial and the speed and trajectory differs for different mental workload levels. The "missile" travels a linear trajectory. Mental workload is increased by increasing the number of parameters that must be accurately controlled for successful interception. For the first level, only launch time need be controlled. At the second level, launch force must also be controlled. At the third level, horizontal launch position must also be controlled. At the fourth level, the slope of the launch trajectory must also be controlled. There is no symbolic version of this task.

### *Divided Attention*

The basic idea for this category is to perform several tasks at once, each of which emphasize a different collection of mental resources (Wickens, 1984). The first mental workload level consists of two tasks, increasing to five tasks for the fourth level. The component tasks of the spatially oriented task family includes the following: (1) a tone detection task; (2) the lowest level spatially oriented Working Memory task; (3) a simplified form of the spatially oriented Visuomotor Tracking task where a button press simply centers the horizontally moving cursor; (4) the lowest level Dynamic Visuospatial Reasoning task; and (5) an arithmetic task adapted from the NATO AGARD STRES battery (AGARD, 1989) In the tone detection task, the computer periodically emits a tone to either the left or right ear, one of which occurs less often. The goal is to respond with a button press when the rare tone (side) occurs. In the arithmetic task, the sum or difference of two graphical columns is to be judged taller or shorter than a reference column. The component tasks of the symbolically oriented task family includes the following: (1) the tone detection task where the tones can be a high or a low sound delivered to both ears; (2) the lowest level symbolically oriented Working Memory task; (3) the symbolic version of the Visuomotor Tracking task, simplified in the manner described above; (4) a symbolic version of the lowest level Dynamic Visuospatial Reasoning task; and (5) the arithmetic task with numbers in place of the graphical columns. In the symbolic version of the lowest level Dynamic Visuospatial Reasoning task, a numerical counter is presented along with a target

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